# SURVEY PROCEDURES FOR IMPROVING WESTERN SPRUCE BUDWORM BIOLOGICAL EVALUATIONS IN THE SOUTHWESTERN REGION

By Robert E. Acciavatti

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Forest Insect and Disease Management
State and Private Forestry
Southwestern Region, Forest Service, USDA
517 Gold Avenue, SW
Albuquerque, New Mexico 87102

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## INTRODUCTION

The western spruce budworm (Choristoneura occidentalis Freeman) has been the most destructive defoliator of Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco) and true firs (Abies spp.) in the Southwestern Region (Lessard 1975). Budworm populations caused severe defoliation over extensive areas of the Region during the late 1950's and early 1960's. Populations declined through the 1960's and have remained at low levels through the early 1970's. However, budworm populations increased dramatically in 1975 and caused noticeable defoliation in areas where the insect historically has been most destructive.

Biological evaluations of budworm infestations from 1959 to 1968 were based on the methods of Carolin and Coulter (1959). From 1968 to 1975, the sequential sampling plan of Knight et al. (1970) was used. Difficulties with the sequential plan involving efficiency of sampling and accuracy of predicting defoliation (Acciavatti 1976) have prompted modification of the present survey system.

This report presents survey procedures for improving biological evaluations of western spruce budworm infestations. These evaluations involve determining the trend of an infestation and defoliation expected from it in the absence of control factors. Two general types of survey procedures will be discussed: aerial and ground. Ground surveys will be divided into egg mass sampling, larval sampling, and tree damage appraisal.

## AERIAL EVALUATION PROCEDURES

Western spruce budworm infestations in the Southwest are most efficiently located and their boundaries delineated from the air. Physiographical features and discontinuous host type combine to limit infestations to rather well-defined areas. These areas have been called "entomological units," and management objectives were also considered in their establishment (McKnight et al. 1970). Each entomological unit should be considered as one sampling universe.

Infestations should be stratified by defoliation severity during aerial reconnaissance flights. Budworm feeding is most noticeable in the upper crowns of host trees during late July and early August. Partially consumed needles and webbed shoots become reddish brown at this time of year, but these eventually fall off the trees, thereby making it difficult to observe damage from the air. Defoliation is most obvious with morning light, as the reddish color of defoliation is washed out by full sunlight.

Aerial surveys to detect budworm should be flown as close to the terrain as safety will allow. Contour flight paths should be made to cover both sides of each drainage and avoid missing any areas of host type. Infestation areas can be mapped adequately using forest maps of $\frac{1}{2}$ inch to the mile which show major drainage patterns.

Once an infestation is located, areas of various defoliation intensities should be delineated using the following criteria adapted from Terrell (1966):

Light - damage varies from barely visible to reddening of uppermost part of tree crown; a few heavily damaged spots throughout the stand.

Moderate - damage clearly visible as reddening of upper half of tree crown; some heavily damaged spots throughout the stand.

Heavy - damage visible on most trees as reddening of entire crown throughout entire stand; some top-killing evident.

These intensities generally fall into the following categories of percent defoliation of current growth: light = <35%; moderate = 35-65%; heavy = >65%.

Aerial surveys should provide a measure of the relative defoliation with each infested area. This stratification can be used to locate samples, provide acreage estimates of defoliation for the biological evaluation, and historical data about changes in the extent and intensity of infestations within a given area. Since aerial estimates apply to the generation which has completed development, they cannot be used to establish infestation trends. Moreover, aerial estimates emphasize cumulative tree damage which may not truly reflect existing populations. Data on population density and trends, as well as defoliation expected the next year, can only be obtained from a ground survey.

## GROUND SURVEY PROCEDURES

The egg stage and instar III larvae in expanding buds have been shown to be most suited for sampling western spruce budworm populations (Carolin and Coulter 1972). During both developmental stages, the populations are stable, easy to sample, and provide reliable forecasts of subsequent new growth defoliation. However, the egg stage provides information about the new generation during the fall in time for project planning and preparation of environmental impact statements, if direct chemical suppression is recommended. Larvae in buds, on

the other hand, provide information primarily about the continued need for suppression, since the spring sampling comes too late to begin planning. Overwintering larvae in hibernacula also may be suitable for deciding if suppression is still warranted; however, adequate sampling techniques and models for predicting defoliation have yet to be developed. Other objectives of ground surveys, such as measuring suppression efficacy, involve techniques for sampling late instar larvae on the foliage, but these will not be discussed in this report.

Egg Mass Sampling

Western spruce budworm egg masses are used to evaluate infestations in most of the western Regions (Tunnock 1972). Population densities are measured, population trends determined, and subsequent new growth defoliation predicted on the basis of egg masses found on Douglas-fir foliage.

Sampling Design.--Infested areas to be sampled should be selected on the basis of aerial survey information. This limits sampling to those infestations which are of immediate concern to the land manager, since infestations with at least 25 percent defoliation are generally the minimum observed from the air. Areas where no defoliation is visible from the air should not be sampled because there is adequate lead time to plan suppression before significant damage occurs. For obvious reasons, therefore, aerial survey data must be available prior to conducting ground surveys. The number of samples to be taken within an infestation depends on the inherent variability of the population, the sample accuracy desired, and limitations on manpower, funding, and time. Population variability is difficult, if not impossible, to control, but can be minimized by limiting sampling to areas where defoliation was observed from the air. Sample accuracy within 20 percent of the mean with $P < .10$ is considered adequate goal; however, limitations on manpower, time, and funding may dictate even less sampling intensity.

Field Collection.--Budworm egg masses will be sampled in August after egg hatch. A minimum of four sample tracts will be scattered throughout each entomological unit. The total number of tracts will vary with the size of the unit. Each tract should be 15-25 acres in size, with homogeneous stand conditions as to host type and stand structure. Within each tract, 8, one-tree subplots will be located along a compass line at regular intervals, such as 5 chains. Since the greatest variability is between areas, this design will better portray population levels.

Sample trees will be Douglas-fir codominants, 50-70 feet in height, and free from top-kill. To reduce personal judgment, the first tree meeting these criteria nearest plot center will be sampled. Each sample tree will be permanently marked to measure defoliation at a future date. Two 24-inch midcrown branches will be cut from opposite sides of each tree with a pole pruner equipped with a basket. The basket will keep the branch from falling through the crown and dislodging egg masses while it is being lowered to the ground. Branches which fall through the crown or are too short will be discarded and replacements taken from the same tree. Branches which are too long should be trimmed in length only. The maximum length and width of foliage on each branch should be measured. Take the measurements perpendicular to each other, round to the nearest inch, and record on Work Sheet 1.

The cut branches are most conveniently handled in $\frac{1}{4}$-bushel paper sacks. Both branches from each tree will be placed in the same sack and labeled as to entomological unit, plot name, and tree number (e.g., Cuba, Blue Bird Mesa, 3). This information should also be recorded on Work Sheet 1. The sacks will be bundled together with strong twine for transport to the laboratory. All sacks will be kept out of direct sunlight during transport and stored in a walk-in cooler (about 40° F) until the foliage is examined.

Laboratory Examination.--The foliage of sample branches will be examined for egg masses in the laboratory by a crew trained to recognize egg masses on needles. All new growth will be cut from each branch at the terminal bud scale scar and kept apart from the rest of the foliage. The old growth will be clipped into workable segments of 6 inches.

New and old growth will be examined separately under long-wave ultraviolet light in a darkened room (Acciavatti and Jennings 1976). Two 15-watt black-light lamps (F-15T8/BLB), mounted in an 18-inch standard desk-type receptacle, will provide the ultraviolet illumination. Ordinary window glass will be taped beneath the lamps to absorb any short-wave ultraviolet light. The lamps will be mounted about 1 foot above a worktable covered with black construction paper to minimize reflected light.

A battery-powered penlight will be used to differentiate fluorescent objects, such as pitch droplets, spider egg cases, and bird droppings, from budworm egg masses.

Needles bearing egg masses will be placed in pill boxes labeled as to entomological unit, plot name, tree number, and foliage age. Branches will be discarded after they have been examined.

All the foliage examination work should be performed under the supervision of a technician or professional who has had experience with budworm egg mass sampling. The crew should be instructed as to their work, and their performance checked periodically for quality. This may involve general observation and/or checks of examined foliage.

The egg masses found on each branch will be classed as new (deposited in the current year) or old (deposited in a previous year). The crew supervisor will make the classification under a stereomicroscope. All egg masses on new growth will be classed as new, and the characteristics of these will form the basis for a more accurate classification of the egg masses found on the old growth. Numbers of new and old egg masses will be counted and recorded for each branch on Work Sheet 2.

Data Analyses.--The foliated branch surface area will be used to convert actual numbers of egg masses found to densities per 1,000 square inches of foliage. Densities of new and old egg masses per branch will be used to compute: (1) an average plot ratio of new to old masses and (2) a "t" value ($P \leq .05$) to determine the plot infestation trend. A significant average density difference indicates definite plot trends depending upon the plot ratio, i.e., $\geq 1$ = increasing or $< 1$ = decreasing. A nonsignificant difference indicates a static situation. The trends for all plots in an entomological unit will be used to ascertain if an obvious trend exists for the infestation.

After the trend has been established, defoliation will be predicted for each entomological unit. The average number of new egg masses per 1,000 square inches of foliage (NEM) for each plot will be used to compute subsequent new growth defoliation (D). The equation $D = 1.65 + 2.12\ (NEM) - 0.023\ (NEM)^2$ with $r^2 = 0.76$ predicts defoliation during "static" infestations, while the equation $D = 14.17 + 3.55\ (NEM) - 0.045\ (NEM)^2$ predicts defoliation during "increasing" infestations (McKnight 1968). Defoliation predictions for "decreasing" infestations can be made from the first equation without serious error. Record the predicted defoliation on Work Sheet 3.

These defoliation predictions apply to average conditions and are generally adequate unless average numbers of eggs per new mass, percent egg hatch, and survival from egg hatch to attack on the buds are abnormally high or low. The norm for egg density, percent egg hatch, and larval survival through instar III can be determined for each entomological unit only after several years of data collection. However, average conditions for these factors may be obtained from published sources. McKnight (1969) indicated egg densities averaged 18 eggs/mass for two-row masses and 33 eggs/mass for three-row masses on Douglas-fir in southern Colorado. Carolin and Coulter (1972) found that an egg hatch of 80 to 90 percent was normal in eastern

Oregon. McKnight (1971) suggested that larval survival through the third instar depended upon egg density. He found that about 84 percent of the survival was accounted for by the equation SE = 9.21 - 1.01 log (NE), where SE = larval survival through instar III and NE = average number of eggs per mass. Thus, it can be seen that egg masses can be examined to determine each of these factors which influence defoliation predictions.

A random sample of 100 hatched new egg masses will be examined from each entomological unit by the work supervisor. Masses will be prepared by modifying the technique of Jennings and Addy (1968) and Leonard et al. (1973) to leave egg masses on the needles during staining, cleaning, and examination. A stereomicroscope fitted with an ocular micrometer will be used to examine each egg mass. All data will be recorded on Work Sheet 4.

The length of each egg mass will be measured to the nearest tenth of a millimeter. The number of rows and total number of eggs will be counted for each mass. For three-row masses, the third row must be at least half the length of the mass. The number of inviable and parasitized eggs will also be counted. The relationship between total number of eggs in a mass and the length of the mass will be analyzed by linear regression for one-, two-, and three-row masses to establish a norm for each infestation.

Larval Sampling

The objective of larval population sampling is to provide an updated estimate of predicted defoliation. This objective can be met by sampling instar III larvae in buds.

Sampling Design.--The same rationale for the design of egg mass sampling will apply for larval sampling. A sampling accuracy of 20 percent of the mean with $P < .10$ will be adequate.

Field Collection.--Budworm larvae will be sampled while they are mining opening buds. This period begins in late May and lasts for only about 10 days before bud burst (Carolin and Coulter 1972). For each entomological unit, two of the egg mass plots and two of the subplots within these will be randomly chosen for sampling. At each subplot, 10 codominant Douglas-fir trees will be sampled. Each sample tree will permanently marked for future reference.

Four 15-inch apical twigs will be cut from the lower crown of each sample tree. One twig will be taken from each cardinal direction. A pole pruner equipped with a basket will be used to lower cut branches to a drop cloth for trimming and examination. The numbers of larvae mining buds and total buds on each 15-inch twig will be counted and recorded on Work Sheet 5.

Data Analyses.--An average larval density per twig will be calculated for each plot. Predicted defoliation (D) based on average larvae number per 15-inch twig (L) for each plot can be computed from the equation: $\log_{10}(D + 1) = 0.11 + 1.62(\log_{10}(L+1))$ with $r^2 = 0.86$ (McKnight 1968). Data for this equation were obtained during "static" infestations and may not apply to "increasing" or "decreasing" infestations. Therefore, defoliation predictions using this equation should be verified by actually estimating defoliation observed on sample trees.

Tree Damage Appraisal

Estimates of western spruce budworm damage are most commonly expressed as percent defoliation of new growth. The incidence of bud-killing is perhaps an even more important damage factor, since continued bud-kill causes branch mortality and top-kill (Carolin and Coulter 1972). These estimates of current damage will be used in the biological evaluations and to adjust defoliation predictions based on egg masses and larvae.

Sampling Design.--Some of the same plots used to sample for egg masses and bud-mining larvae will be appraised for defoliation and bud-killing. The number of trees appraised will depend upon manpower, funding, and time limitations, but at least half the trees originally sampled for egg masses and half of those sampled for larvae should be appraised within each entomological unit. These damage appraisals should be made after larval feeding ends. Thus, appraisals can be made most economically during egg mass sampling.

Field Collection.--Field-glass estimates of current defoliation on each sample tree, supplemented by shoot and bud examination, gave the most efficient and accurate tree damage estimates (Carolin and Coulter 1972).

Defoliation estimates will be made with field glasses using the following procedure developed by Carolin and Coulter (1972):

1. Two observers independently divide each tree crown into thirds visually.

2. The percent defoliation of current growth for each crown third is estimated independently by each observer and classed as follows: 0-10, 11-25, 26-50, 51-75, 76-90, 91-100. Start by asking if the defoliation is more than or less than 50 percent.

3. The midpoint of each class is determined and the two estimates are averaged for each crown third.

4. Multiply the average midpoint for each crown third on the basis of proportional foliated branch area as follows: lower - 1; middle = 3; upper = 5.

5. Total the weighted averages and divide by 9 to get an average defoliation estimate for each tree.

Record all defoliation estimates and computations on Work Sheet 6.

Laboratory Examination.--Damage estimates based on examining shoots and buds will be made from the new growth collected during egg mass sampling. One hundred new shoots will be randomly selected from each tree. Each shoot will be checked for defoliation and killed buds. Budworm defoliation is recognized then by partially consumed reddish needles or bare shoot tips where the needles have fallen off. A killed bud lacks living tissue. The number of shoots with defoliation damage and killed buds will be counted and recorded for each tree on Work Sheet 7.

Data Analyses.--The percent current defoliation for each tree as estimated with field glasses will be compared with the predicted values. These estimates will be combined with those from previous years to refine the basic equation. These refinements should improve budworm defoliation predictions in the Southwestern Region during "increasing" infestations.

Estimates of percent current defoliation from shoot measurements will be obtained from McKnight (1969). The percent of bud-killing will also be determined. These latter two estimates more accurately appraise damage when high budworm populations defoliate 85 percent or more of the current growth (Carolin and Coulter 1972).

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# A P P E N D I X

WORK SHEET 1.--WESTERN SPRUCE BUDWORM EGG MASS SURVEY-FOLIAGE SURFACE AREA

Entomological Unit _____

Plot Name _____

Date _____ Sheet ___ of ___

| Tree number | Branch number | Branch size | | Foliated surface - sq. in.[1/] |
|---|---|---|---|---|
| | | Length | Width | |
| 1 | 1 | | | |
| | 2 | | | |
| 2 | 1 | | | |
| | 2 | | | |
| 3 | 1 | | | |
| | 2 | | | |
| 4 | 1 | | | |
| | 2 | | | |
| 5 | 1 | | | |
| | 2 | | | |
| 6 | 1 | | | |
| | 2 | | | |
| 7 | 1 | | | |
| | 2 | | | |
| 8 | 1 | | | |
| | 2 | | | |

1/ $\frac{\text{Length X width}}{2}$

WORK SHEET 2.--WESTERN SPRUCE BUDWORM EGG MASS SURVEY-EGG MASS DATA

Entomological Unit _____

Plot Name _____

Date _____ Sheet ___ of ___

| Tree No. | Branch No. | Foliated surface-sq. in. | Egg masses | | | | Plot ratio New:Old | Plot population trend 1/ |
|---|---|---|---|---|---|---|---|---|
| | | | New | | Old | | | |
| | | | Actual | Per 1000 in.$^2$ | Actual | Per 1000 in.$^2$ | | |
| 1 | 1 | | | | | | | |
| | 2 | | | | | | | |
| 2 | 1 | | | | | | | |
| | 2 | | | | | | | |
| 3 | 1 | | | | | | | |
| | 2 | | | | | | | |
| 4 | 1 | | | | | | | |
| | 2 | | | | | | | |
| 5 | 1 | | | | | | | |
| | 2 | | | | | | | |
| 6 | 1 | | | | | | | |
| | 2 | | | | | | | |
| 7 | 1 | | | | | | | |
| | 2 | | | | | | | |
| 8 | 1 | | | | | | | |
| | 2 | | | | | | | |
| | Totals | | | | | | | |
| | Avg. | | | | | | | |

1/ I = Increasing; D = Decreasing; S - Static

WORK SHEET 3.--WESTERN SPRUCE BUDWORM EGG MASS SURVEY-PLOT SUMMARIES

Entomological Unit _____

Date _____

| Plot name | Plot population trend | New egg masses per 1000 in.$^2$ of foliage | Predicted defoliation |
|---|---|---|---|
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WORK SHEET 4.--WESTERN SPRUCE BUDWORM EGG MASS DENSITIES

| Egg mass number | Length mm | Number of rows | Total Number of eggs | Number of unhatched eggs |
|---|---|---|---|---|
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WORK SHEET 5.--WESTERN SPRUCE BUDWORM LARVAL SAMPLING-LARVAE IN BUDS

Entomological Unit _____

Plot Name _____

Date _____ Sheet ___ of ___

| Tree No. | Twig No. | No. of larvae in mined buds | Total living buds | Larvae per 1000 buds | Percent Douglas-fir defoliation | |
|---|---|---|---|---|---|---|
| | | | | | Predicted | Actual |
| 1 | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 4 | | | | | |
| 2 | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 4 | | | | | |
| 3 | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 4 | | | | | |
| 4 | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 4 | | | | | |
| 5 | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 4 | | | | | |

WORK SHEET 6.--WESTERN SPRUCE BUDWORM TREE DAMAGE APPRAISAL-
FIELD-GLASS ESTIMATES OF CURRENT DEFOLIATION

Entomological Unit _____

Plot Name _____

Date _____ Sheet ___ of ___

| Tree No. | Crown Third-Weight | Percent current defoliation | | | | |
|---|---|---|---|---|---|---|
| | | 1st observer | 2nd observer | Average | Weighted average | Tree average |
| | Lower-1 | | | | | |
| | Middle-3 | | | | | |
| | Upper-5 | | | | | |
| Total | 9 | | | | | |
| | Lower-1 | | | | | |
| | Middle-3 | | | | | |
| | Upper-5 | | | | | |
| Total | 9 | | | | | |
| | Lower-1 | | | | | |
| | Middle-3 | | | | | |
| | Upper-5 | | | | | |
| Total | 9 | | | | | |
| | Lower-1 | | | | | |
| | Middle-3 | | | | | |
| | Upper-5 | | | | | |
| Total | 9 | | | | | |

WORK SHEET 7.--WESTERN SPRUCE BUDWORM TREE DAMAGE APPRAISAL-
DAMAGED SHOOTS AND KILLED BUDS ON NEW GROWTH

Entomological Unit _____

Plot Name _____

Date _____ Sheet ___ of ___

| Tree No. | Type of damage | Number damaged | Total number | Percent damaged | Percent Douglas-fir defoliation |
|---|---|---|---|---|---|
| | Shoots | | | | |
| | Buds | | | | |
| | Shoots | | | | |
| | Buds | | | | |
| | Shoots | | | | |
| | Buds | | | | |
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